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SOFTWARE AND METHODS FOR AUTOMATED PALLET REPAIR

Field of the Invention

The present invention relates generally to the repair of wooden pallets, and specifically to an automated process for scanning pallets and identifying individual elements of the pallet for removal, replacement, or repair. It is also applicable to pallets constructed from other materials such as plastic, metal or composites.

Background of the Invention

Commercial movement of materials typically use a wooden pallet on which the material is placed or secured. This pallet is typically constructed with a flat upper deck consisting of planks or boards of timber nailed, screwed, or glued to parallel beams known as bearers or stringers. Bottom boards are similarly attached to the bearers. The framework allows the insertion of the "forks" of a forklift or other machine to raise and move the pallet and its load of materials. There are several pallet designs in use and are distinguished generally by place of manufacture and use. For example, pallets made and used in Australia, New Zealand, the United States, Canada, and Europe are all of different designs. In some designs, blocks are used with or in place of bearers to separate the top and bottom boards.

During normal use, the pallets may be dropped, overloaded, crushed or otherwise damaged. Damaged pallets are often returned to the pallet provider or pooler for inspection, repair or replacement.

The inspection and decision process is currently done by skilled human inspectors or by automated means that implement the specific criteria, and decide to repair or discard a damaged pallet. Using human inspectors is desirable because they can inspect and immediately repair each pallet at a single station. This can be done by presenting each damaged pallet in turn, for example, on a conveyor, such that the inspector can see pallet damage and repair it if necessary. It is undesirable because the inspection and repair

decision is not uniform as each inspector will naturally implement repair based on his or her judgement. It is also undesirable from a safety point of view as accidents will happen in such an environment.

Current automated systems use stereoscopic pairs of cameras to collect pallet geometry and topography information, then use computer programmes to make a repair / discard decision by uniformly implementing the specific pallet criteria. This is done by first determining the pallet's design, e.g. Australian or European, and comparing the geometry and topography of the individual pallet against criteria for the pallet's design. Current systems, however , decide only to repair or discard each inspected pallet, that is, each pallet either does or does not pass the inspection criteria. If the pallet passes, it is placed back in service. If it does not pass, it is sent for repair. The repair process, however, is similar to the manual inspection process above. The pallets needing repair are sent, for example, by conveyor, past one or more human repair stations where the repairer inspects the pallet, determines what needs repair and then repairs it. This has the same disadvantages in uniformity and safety of the human inspection process. It is faster, however, since the human inspectors are seeing only those pallets determined to need repair.

Objects and Summary of the Invention

It is an object to provide an automated process which not only inspects pallets and determines when to repair or discard, but also identifies the pallet element or elements that need to be removed, replaced, or repaired, and passes this additional information to a human or automated repairer.

It is therefore an object of the present invention to automatically inspect pallets, identify the pallet design, compare that geometry and topography of the pallet against pre-defined quality criteria, determine when to repair or discard, identify specifically the element or elements needing repair and the exact nature of the repair needed.

It is another object of the present design to provide the repair data to an automated repair process, thus eliminating both human inspectors and human repairers. This makes the process of pallet repair faster, safer, and more uniform than current methods.

In summary of one embodiment, without being considered a limiting example, a pallet to be inspected is moved relative to an inspection head. This may be on a conveyor or using a robotic manipulator or other device. Alternatively the pallet may be in a stationary location and the inspection head may move across it. In preferred embodiments, the sensing head consists of a set of at least one laser and a camera, with the camera recording the projected laser profile across a width of a pallet. Extra cameras can be used to help scan wider areas but stereoscopic camera pairs are not needed. Resulting information from the sensing head is collected and processed to represent the geometry and topography of the pallet. A two dimensional representation of the pallet is analysed so that the individual elements are identified and located by coordinates. The pallet design is determined by the number, size, and location of the elements. The elements are analysed against specific criteria for the pallet's determined design. This includes criteria for the element alone (size, location, integrity, damage, missing or raised nails, etc.), inter-elemental criteria (spacing, overlap, etc.), and pallet design criteria (missing or superfluous elements, etc.). If the pallet is determined to have not passed the criteria, a recipe or list of specific repairs is generated. This list includes which element is to be repaired and the nature of the repair (remove, replace, reattach, repair, etc.). The data comprising the list of repairs to be made accompanies the pallet to the repair station. In preferred embodiments, the repair station is an automated repairer, for example, a robot arm using a nail gun, band or other saw, prying levers, etc., to implement the exact repairs determined necessary. After repair, the pallet is returned to service.

In preferred embodiments the present invention provides coordinate outputs sufficient to automate, through robotic arm for example, the component repairs.

Brief Description of the Drawings

Figure 1 is a schematic top plan view diagram of a pallet;

Figure 2 is a schematic top plan view diagram of an inspection station;

Figure 3 illustrates a schematic side elevation of a pallet; and

Figure 4 illustrates a logic flow chart of a pallet repair process.

Detailed Description

Figure 1 illustrates one design of a pallet 100. The pallet consists of top boards 102, labelled TB 0 through 7, and corresponding bottom boards labelled BB0 through BB4. The top boards are supported by three horizontal bearers or stringers 104, 106, and 108, labelled B0, B1 and B2. Other designs will have different numbers of boards, different sized boards, and different spacing between boards, and may have different numbers and styles of bearers. Blocks and connector boards may be substituted for bearers in some designs. In the illustrated design, top board 0 and top board 7 are wider than the other six boards. For the purpose of this invention the pallet can be considered to be laid out in an orthogonal x y z configuration where the x axis runs horizontally (with reference to Figure 1) across the bottom of the pallet parallel to beam or bearer 108. The y axis runs vertically (with reference to Figure 1) along the left edge of top board 1. The z axis is orthogonal to both x and y.

There are four processes which make up the preferred method of automated pallet inspection and repair. Each will be discussed below. The first step is data capture. This means capturing all of the data about the physical or structural make up of a pallet which is required to make the determinations about the nature, extent and order of the repair process. The next step is the analysis of the captured data. The analysis simplifies the data and relates the data to known facts so that a repair process, using certain fixed processes can be specified. Next is a process of generating a recipe or list of process based on what repair processes are available and what repairs are needed based on the data and analysis of it. After recipe generation is the last major step, that of the

implementation of the recipe using automated equipment. In preferred embodiments, an industrial robot reads a step specified by the recipe and implements that according to a flexible programme before implementing the next step of the recipe.

The present invention consists of (for example) two computer systems and a mechanical means for moving pallets. These systems may reside on one or more physical computer processors or hardware, and may be distributed or collected. The first computer system is called the capture system, which collects information about the geometry and topography of the pallet. The second computer system is called the analysis system, which analyses the geometry and topography of the pallet and determines the pallet design and then using the pallet design specifications analyses the pallet and decides whether it is to be repaired or returned to service. It is not required that the tow computer systems be separate or distinct. The mechanical means moving the pallet may be a conveyor belt or a robotic arm or other system for transporting the pallet through the inspection head.

Figure 2 illustrates one implementation 200 of the mechanical means for moving pallets. This comprises a chain conveyor supporting a pallet 204 and moving it in the direction of the arrow, left to right. The pallet 204 moves under twin lasers 206 and 208. These lasers illuminate and sensors capture the entire width of the pallet 204. In some embodiments there is an overlap in the laser beams in the middle as shown by 210. As the pallet 204 moves under the lasers 206 and 208, information about the geometry and topography of a pallet is captured by cameras and sent to the capture computer system 212. Such laser and sensor systems are well-known, as are the methods for using such lasers to collect this information. The system may be replicated to collect data on the other faces of the pallet simultaneously or asynchronously from the top deck. It will be obvious that this may also be achieved using a different number of laser and camera combinations than the twin set up described above.

The capture computer system 212 performs the following steps. First it collects the profile information of the pallet, that is, it collects the geometry and topography information from the lasers and sensors. The sensors return a stream of three-

dimensional coordinates. The cameras/sensors are synchronised so that overlapping points illuminated by multiple lasers give the same coordinate values when viewed from each sensor or camera. The scans from the two lasers are then combined to give a set of coordinates for the entire width of the pallet. This process is repeated for each profile scanned as the pallet moves relative to the lasers and cameras

When analysing the top deck, the scanned data is filtered to give only the top surface geometry and topography. This is accomplished by discarding any points which have a z-coordinate which is below a given threshold or filter line. This removes from analysis any point corresponding to a bearer or the bottom of the pallet or the transporting conveyor or robotic manipulator, for example. It will be obvious that the same process could be applied when analysing any specific face or deck of the pallet.

In some embodiments, individual planes are established for each bearer. The planes can be combined, averaged or used as separate data references.

The laser scans are timed according to the speed of the pallet transport mechanism so that scans occur at regular distances along the length of the pallet in the direction of movement. Typically, this is set to scan at 1mm linear distance, though it could be at any chosen resolution distance.

Next, the corner points of the pallet are found using a 45 degree filter. This locates the four points at the extremities of the pallet. That is, it finds the point of minimum x minimum y, minimum x maximum y, maximum x minimum y, and maximum x maximum y. These four points determine the corners of the pallet. These are typically referred to as PP0, PP1, PP2, and PP3 respectively, where PP0 and PP2 lie on the x-axis, and PP0 and PP1 lie on the y-axis. PP0 and PP3 are diagonally, as are PP1 and PP2.

Next, it finds the offsets between the image origin and pallet origin to give the x and y offset distances of the pallet. That is it calculates the size of the pallet by subtracting

combinations of PP0, PP1, PP2, and PP3. The data is also normalised by relocating the coordinates so that PP0 lies at the origin of the pallet coordinate system, and PP1 and PP2 lie on the x- and y-axis respectively. A second set of coordinates, based around the image datum, is used when calculating automatic repair parameters.

To convert from the three dimensional topographical information to a two dimensional geometric representation, first the locations and heights of the bearers (labelled B0, B1, B2) are found in the image by inspecting the profiles most likely to represent bearer locations.

When the bearer heights and locations have been determined, a series of filter planes is drawn offset from the bearers (shown as element 302 in Figure 3). Each point in the three dimensional representation is then checked against the corresponding filter plane. Points above the filter plane are identified as belonging to boards, points below belonging to bearers or other structural elements. The board points are then further filtered and assembled into arrays of points on board edges belonging together. This can be done using any standard edge finding technique applied to the set of points above the filter line and an edge chain following algorithm. These edge arrays represent boards or parts of boards and are used in later analysis. If a two dimensional (geometry only) scanning and inspection head is used, electronic means (eg sensor range restrictions) are used to filter the boards from other data, with the same array identification and assembly process taking place. The arrays do not contain height related data, only 2D geometrical position of points above the filter line.

The analysis computer system 214 performs the steps shown in Table 1.

TABLE 1

Step	Description
1	The data stream from the inspection head is captured to construct a pallet model in computer memory. This process uses the known resolution o the inspection head and the known pallet velocity and distance from the sensing head to construct a three dimensional topographic model and subsequently a two dimensional geometric model of the pallet being analysed. Pallet corner points are calculated from topographical data and stored.
2	Geometric model is broken down to give arrays of points representing the edges of each board (and edges of partial boards)
3	Board arrays are checked for completeness (i.e. is the edge a closed loop?) and consistency (i.e. edges do not cross) Joined boards are split by applying a virtual edge along the most probable line of intersection between the boards. Where there are multiple arrays along a single line drawn parallel to the Y axis and these arrays are all less than a full board length in the Y direction and not overlapping or intersecting, they are classed as a single (broken) board. Board arrays are then sorted by their minimum X value, and their corner points are identified and stored.
4	By comparing the number, type and location of identified boards and the separation distance between pallet corner points with the range of possible known pallet geometries, a pallet type can be assigned to the pallet undergoing analysis, determined by the closest match against the database of specifications. This matching process can be accelerated if the system need only expect a single pallet style. A pallet that can not be matched to a specific pallet style is marked as undefined and further analysis on it is halted.
5	Board types can be assigned (eg Intermediate, Lead, etc) to each board based on its location relative to pallet corner points and its approximate width (from board corner points). Boards within a specified region of the pallet corner points are presumed to be lead boards.
6	Pallet quality criteria are loaded from the database into the analysis system for the particular pallet type determined above. Each board array can be checked against the appropriate board criteria for that board type. Board checks may include board width, notches or missing material, jagged edges, excessive crookedness, or any other criteria. Any board array that fails these tests is marked as a board to be removed. Topographic data for the region corresponding to the board is also checked for board thickness, end splitting, cracks, holes and other three dimensional features, with failures again being recorded for removal.
7	Examine the board arrays against other quality criteria to determine if other non-removal board repairs are necessary. An example would be the position of the lead boards relative to the pallet corner points, with any lead board that is too far from the corner points marked to be adjusted, unless it has already been marked for removal. A hierarchy of board repair decisions is imposed with the board removal the highest precedence, board realignment next, and any other operation lowest.
8	Gaps are checked against gap criteria, such as gap width. Gaps that are larger than a board width are checked to see if a board will allowably fit into the gap with appropriate resulting gaps on either side (Fig 4). If a board will fit, a phantom array is constructed to represent the missing board, and it is marked for a board placement operation.
9	All results are stored in the database. At this point, all arrays are marked as either valid boards, or as boards to be removed, adjusted or operated on.

10	When this system is implemented in an automated pallet repair situation, further calculations and data manipulation are required. These calculations are specific to each machine in the repair cell, and might include the location (X, Y & Z position and angles) required to insert a bandsaw blade into a particular gap to perform the removal operation for a board that has been marked for removal. Where this blade does not fit into the gap, the board is marked for removal with a different device.
11	A recipe is generated for the repair cell, with a list of operations (jobs) required to be performed to repair the pallet, and the associated data for each of these jobs. These are sorted to expedite the repair cycle time
12	In an inspection system designed for sorting or for quality control purposes only, steps 10 and 11 are removed, and replaced by further topographic analysis of protruding nails and other features.

Fig. 4 illustrates the logic flow for step 8 in Table 1, the process for examining the gaps 400. The software defines the storage arrays to hold gap values to use for each of the profiles 402. Each gap is initialised to zero. Starting with the right hand edge of the left most board, the gap values are calculated for each board as shown in step 404. In step 406 the gap values for each board have been stored, so the average gap can be calculated. In step 408 the average gap is compared against the criteria for gap based on the pallet design. If the gap is larger than the design criteria, the gap is marked as a bad gap, shown in step 418. In step 420, the bad gap is examined to see whether it is large enough to fit a new board. If it is large enough to fit in a board, step 424 calculates how many boards will fit into the gap. That number of boards is then indicated for the repair orders. The software then moves to step 422 to examine the next gap. However, if the decision made at step 420 is that the gap is not wide enough to fit in the new board and it still exceeds the criteria for the maximum gap, then step 428 is performed. Step 428 determines which boards must be removed and replaced to fix the gap.

In step 430 a check is made to see if one of the bounding boards is crooked. If the bounding boards are crooked, the offending board is indicated for removal and replacement or repositioned, and the resulting gap is re-evaluated 426. If none of the bounding boards are crooked 430, then a check is made to see if one of the boards is missing any wood (or other material for non-timber pallets) 432. If one of boards is missing material, 432, an order is indicated to remove the board and re-evaluate the

resulting gap in step 426. In step 432, if no boards are missing any material, then step 434 is performed. A check of the neighbouring gaps is made. If one of the neighbouring gaps is smaller than the other then an order is indicated to remove the board and re-evaluate the resulting gap step 426. If in step 434 the gaps are equal size then step 436 is performed, that is, the pallet is marked for manual inspection, or alternatively a decision can be made to arbitrarily remove one of the boards.

With reference to step 408, the average gap is compared against the design criteria, and if the average gap is acceptable, a test is made to determine if there is a notch in the board. Such a notch would give a false indication of a bad gap. The notch test is shown in steps 410 through 416. At 410, the gap values across the notch length are added and the average calculated. In step 416, the calculated average is compared to the design criteria. If the average is greater than the design criteria and the gap is too big processing continues to step 418 described above. If at step 416, the average gap passes the test against the design criteria that a check is made in step 414 to determine if there are more gap values to check. If there are more to check, the step 412 is performed to add the next value and then subtract the first value and recalculate the average. Processing then continues and step 416. If at step 414 there are no more gap values to check, then it has been determined that all gaps values are acceptable and processing continues at step 422 to move to the next gap. If there are no more gaps to test, then processing ends at step 438.

Returning now to step 426, a repair order indicates the removal of a board or the reposition it. Processing then continues at 404 to recalculate the average gap.

In this way, the pallet is examined board by board and repair orders are stored for later use or the pallet is returned to service. If the pallet needs repair, specific instructions are determined for removing, replacing, repositioning boards, or to add one or more boards, or to remove a protruding nail.

This provides a technical advantage over current automated pallet inspection and/or repair systems, which only determine a pass-fail decision for the pallet's suitability, and no specific repair instructions are generated. In addition, the technique of the present invention is sufficient to automate the repair process by connecting the output of the process to an automated repair station. Such a station could comprise a robot arm which grasps the pallet to be repaired, then, using a band saw and nail gun and other devices, removes and replaces specified boards. The instructions to the robot arm would be to, for example, "remove the board located between 22.5 cm and 40 cm from the leading edge, then nail a new board at 22.0 cm from the leading edge."

This same logic may be applied to the inspection of and repositioning of or replacement of the bearers, or alternatively to the lower deck of the pallet.

Controlling the robot in an automated repair cell based on the information generated by the pallet analysis system described above requires specific robot, PLC and computer system linkages or interfaces and software.

Traditional robot control design is relatively simple, based around the premise that the robot performs a repeatable job (or series of repeatable jobs) that can be predefined at the time the system is designed. Further, traditional robot systems require human intervention when there is a problem or a robot crash. To use a robot for pallet repair, it must dynamically change its program for each pallet to be repaired, based on the particular operations required and the location of the boards or gaps to which these operations must be applied. Further, it must automatically recover from problems and minor crashes, and flag major crashes to an operator.

To achieve this, the software system for cell control is broken into three components – these are the robot controller, the programmable logic controller (PLC) and the repair recipe generation sub-system described in Steps 10 and 11 of Table 1. The recipe generation sub-system loads the necessary robot operations and associated position data

into the PLC. This can be done in a single batch for a whole pallet, or sequentially as required. In preferred embodiments the data is sent as a single batch. Data is checked for consistency and completeness, and any missing data is flagged to the recipe generation system.

The robot controller contains a master job and a series of sub-jobs that the master job can call when required. The master job communicates with the PLC. The PLC tells the master job on the robot controller which sub-job to call, and sends it the data that this sub-job will need to run, for example the location and angle of a particular board to be operated on. This data is confirmed by the master job to the PLC, with the master job waiting for a handshake from the PLC before continuing. On receipt of the handshake, the sub-job is called. The first task in each sub-job is to check the robot's current location. The position and angle of the pallet gripper must be within a certain envelope (which may be a sphere or a cylinder around a predefined point or line known as the sub-job home position) for the operation to continue. If the robot is within the allowable envelope, the sub-job continues with the operation. At each step of the operation, a handshake is exchanged with the PLC. This handshake allows the PLC to monitor the point in the sub-job that the robot is up to, which is required for any automatic recovery operations. When the sub-job is finished (or if an error is encountered) control of the robot is passed back to the master job, which communicates with the PLC to get the next sub-job, and the process continues until the recipe is complete.

Each device in the repair cell is numbered, starting with device 02 and working up to device 99 (this system could be extended to use any number of digits depending on the number of devices in the cell, however two digits are used in preferred embodiments). Robot sub-jobs that occur at each of these devices are named after the device where they occur, eg a two digit code. The sub-jobs that control travel between machines are named by combining the names of the two devices between which the robot must move (eg the sub-job for moving from machine 12 to machine 34 would be 1234, whereas to move from 34 to 12 would be 3412). These numbers are generated by the repair recipe sub-

system and passed as part of the recipe. The PLC then passes these names in turn to the robot master job, which then calls the matching sub-job.

Some numbers are reserved for emergency or other recoveries, namely devices 00 and 01. This allows recovery sub-jobs to be defined for each device as XX00 and XX01 where XX represents the device name. Recovery jobs generally reverse out through the steps previously performed at that machine, back to the robot home position for that device (eg if sub-job 03 runs into trouble, the recovery job would be 0300 or 0301, depending on the alarm generated). Depending on the alarm condition, the current recipe step is tried again, or the alternatively the recipe is changed dynamically to overcome the problem. For example, if the removal of a board to be removed with device 03 fails, and device 04 is also designed to remove boards, extra steps can be added to the recipe dynamically to take the pallet to device 04 and perform the removal operation. Depending on the particular recipe, this action may take place immediately, or after the completion of any other pending operations at device 03.

The system relies on the PLC being in ultimate control at all times, and for handshakes between the robot and the PLC between any operations, no matter how small. For safety purposes, all robot operations must check their start position and confirm this with the PLC.

An alternative embodiment of the recipe system would be in a repair cell where the pallet is held in a single location and the inspection head and repair devices are brought to it. The pallet analysis would proceed as per the earlier description, as would the recipe generation. In this style of embodiment, rather than the PLC instructing the robot to take the pallet to a particular repair device, the PLC instructs the robot (or other manipulator) to bring the repair device to the pallet. The transfer of position data is identical to the above description, as are the handshaking and robot location checking procedures.

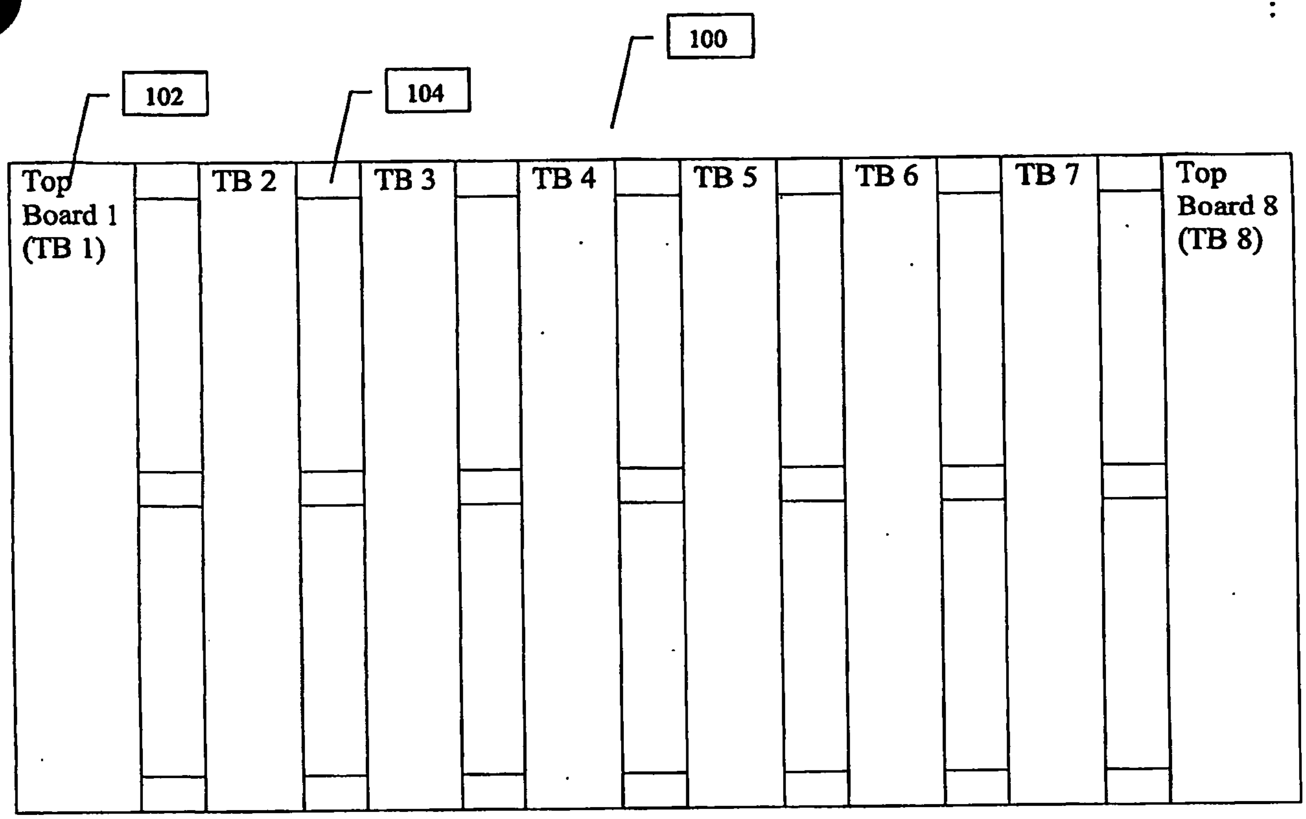

Figure 1

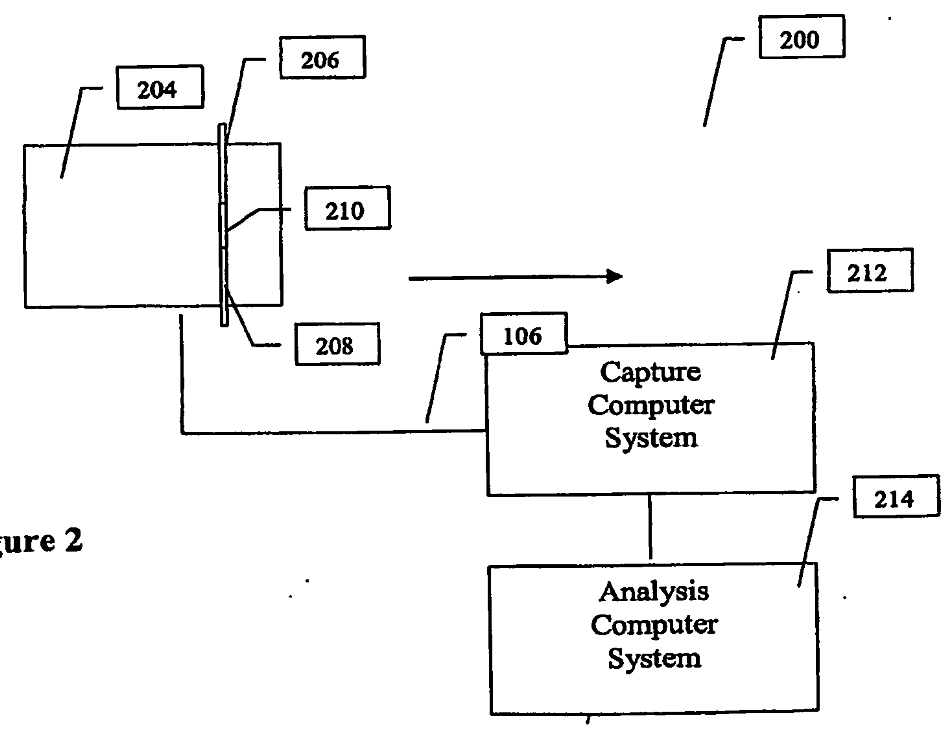

Figure 2

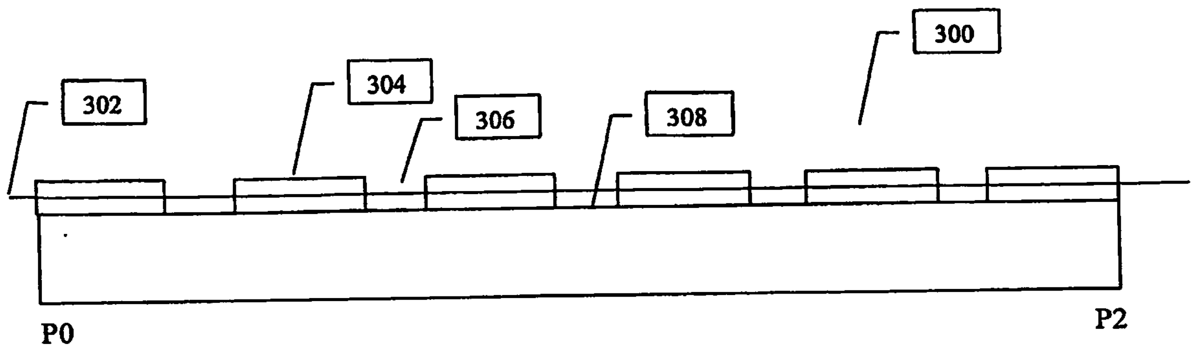

Figure 3

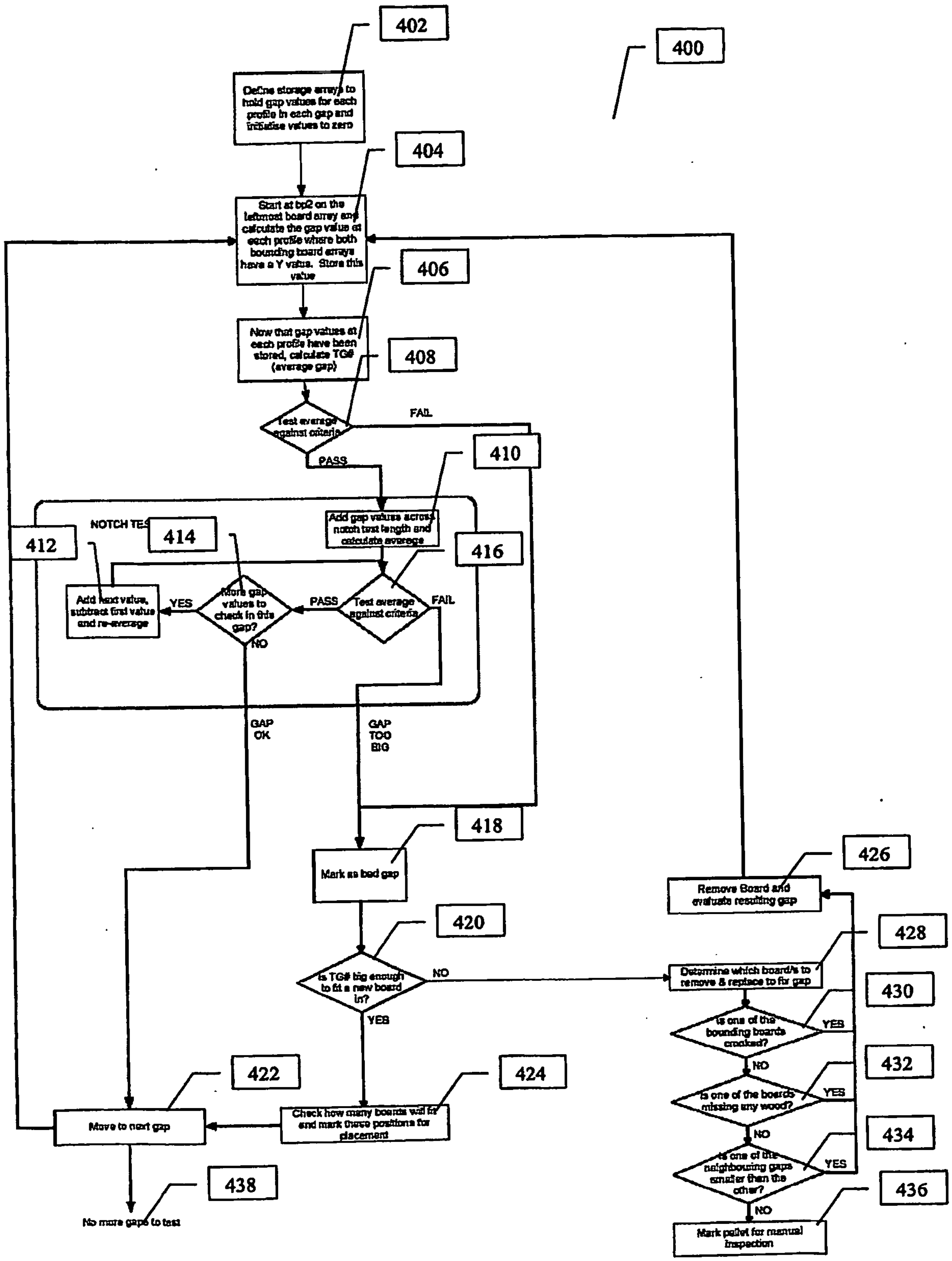
400
402
Define storage arrays to hold gap values for each profile in each gap and initialise values to zero
404
Start at bp2 on the leftmost board array and calculate the gap value at each profile where both bounding board arrays have a Y value. Store this value
406
Now that gap values at each profile have been stored, calculate TG# (average gap)
408
Test average against criteria
FAIL
PASS
410
Add gap values across notch test length and calculate average
NOTCH TES
412
414
416
Add next value, subtract first value and re-average
YES
More gap values to check in this gap?
PASS
Test average against criteria
FAIL
NO
GAP OK
GAP TOO BIG
418
Mark as bad gap
420
Is TG# big enough to fit a new board in?
NO
YES
422
Move to next gap
424
Check how many boards will fit and mark these positions for placement
438
No more gaps to test
426
Remove Board and evaluate resulting gap
428
Determine which board/s to remove & replace to fix gap
430
Is one of the bounding boards crooked?
YES
NO
432
Is one of the boards missing any wood?
YES
NO
434
Is one of the neighbouring gaps smaller than the other?
YES
NO
436
Mark pallet for manual inspection

Figure 4.

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